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PRELIMINARY STATISTICAL REPORT ON THE OCCURRENCE OF MARINE COPEPODA IN THE PLANKTON AT LA JOLLA, CALIFORNIA

BY

CALVIN O. ESTERLY

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CALVIN O. ESTERLY

(Contribution from the Scripps Institution for Biological Research, La Jolla, California)

This paper summarizes some of the results of two years of plankton collecting from the pier at the Scripps Institution for Biological Research of the University of California at La Jolla, California. The series consists of 3471 hauls extending from September 1, 1916, through August, 1917. All hauls were made at the surface of the water, using a conical plankton net of either No. 12 or No. 9 silk bolting cloth. The mouth of the net was fourteen inches in diameter and the length of the filtering portion about thirty-four inches. In making the collections the net was tied to a cord and towed from the end of a pole held over the edge of the pier. The distance it was hauled was about 80 feet, beginning about 100 feet from the end of the pier. A wide-mouthed four-ounce bottle was tied into the peak of the net so that upon draining the net the catch was swept into the bottle.

Hauls were taken six times in twenty-four hours: at 8 A.M., noon, 4 P.M., 8 P.M., midnight, and 4 A.M. In very rough weather the collecting was omitted, and it was agreed that there need be no towing between 4 P.M. on Saturday and 8 P.M. on Sunday. Occasionally emergencies arose that prevented hauling, but on the whole the program was adhered to very well.

The author is responsible for the counting and identification of the Copepoda. The method of counting that was used throughout was, of course, one of sampling. The fluid in the bottle was decanted until a small amount, merely enough to contain the catch, remained. This residue was poured into a watch dish and the contents concentrated by shaking the dish rapidly back and forth without lifting it from the table. It is possible to gather quickly into a compact mass objects as relatively heavy as copepods. If the haul was a small one copepods of the size of *Acartia* and larger were all counted. But in most cases there were too many to permit of counting them all; so

after the haul was concentrated the material was divided into two portions as nearly equal as possible, one of which was removed with a pipette. The remaining portion was shaken together again and half of it removed, if there still were too many organisms left to make fairly rapid counting possible. This procedure was repeated as often as was necessary in order to reduce the amount to be gone over to a point where enumeration would not be an unreasonable burden. In the final counting the numbers were increased in proportion to the numbers of parts into which the whole haul had been divided; that is, if the haul had been divided into eight parts, the number in the one-eighth counted was multiplied by eight to give an estimate of the total number in the haul. Before any division of the collection was made it was looked over for rare or unusual forms. Note was also taken of the relative numbers of copepods that usually occurred, and if it was apparent that one sort was abundant while another was scarce, the number of the latter was estimated upon the basis of a larger fraction of the whole (if the entire number was not counted) than was used in the case of the more numerous form.

It is fully realized that this method of counting is inaccurate so far as giving the numbers of animals actually present in a collection is concerned. That, however, was not the information most desired when the work was planned. The aim was to ascertain the *relative* numbers of different organisms under different conditions in regard to years, seasons, months, times of day, temperatures, salinities and other possible factors. Those of us who have been concerned with the project from the beginning believe that this method of enumeration is adequate to throw a good deal of light on the problem of variations in numbers of the plankton copepods; and other members of the staff concur in this view. Even when every allowance is made for errors in counting, the number of hauls and of animals taken is so large that the errors are bound to balance one another. The crudity of the method is fully understood, and the numbers of animals set down in the tables are not thought of as important except in indicating relative abundance. The method does make it possible to work fairly rapidly and with a minimum of fatigue. There is no reason to suppose that any errors that may have occurred in the counting are systematic, though the extent of any one error may be large as regards actual numbers of animals involved. If one accidental error was made, others of the same sort must have occurred many times. But accidental errors tend to become eliminated as the number of observations increases, while, in the long run, systematic errors do not disappear.

The opportunity for another possible fault in this series should be recognized, namely, the method of collecting. The towing was done by seven different men, some of whom took the night hauls while others took the day hauls. Some worked on alternate weeks for a part of the two years and others worked week after week consecutively. It need hardly be said that changes in the personnel sometimes occurred, so that new men had to work into the routine. There is no doubt that it would have been better if the collecting could have been done by the same two persons throughout the two years, but that was impossible. Perhaps there really are variations in the size of the catches, which are due to differences between the persons handling the net; but it seems very unlikely that in the long run such causes could have had any appreciable effect upon the final results. If one were to set about deliberately to obtain a larger or a smaller haul, practically all he could do would be to tow the net for a longer or shorter distance, or faster or slower. The understanding was that the net should be pulled through the water only fast enough to keep the cone extended, and no faster. This condition was easily complied with in the daytime, but at night it was hard to tell whether the net was moving fast enough. I know from experience that it would have been hard to pull the net at the end of the pole much more rapidly than was necessary to keep it extended. When we consider the large number of hauls made and the length of time through which the series extended, it is hard to see how personal differences could have affected the general results.

Night collecting was subject to a source of error that did not affect the day towing. Sometimes in lowering the net into the water, air would be caught in the peak so that the end holding the bottle was out of water. This difficulty could be overcome in the daytime, but it is hard to tell how often it happened without detection during the night towing. It is certain, however, that we have hundreds of night hauls that were taken with the net properly submerged.

In connection with this work no account has been taken of possible variations due to clogging of the nets. It is well known that new nets catch more than old ones. Our nets were used as long as they were not torn. If thought worth while, it might be possible to ascertain whether there is any constant relation between size of catch and condition of the nets, since the change from 'old' to 'new' is noted in the log books.

Such factors as depth of water due to tide, currents, wave action, sand, wind velocity, and possibly other factors may have affected

relative abundance of the animals, but so far as this summary of results is concerned they have been neglected. It is worth noting that records were taken with the tide-recording machine for long periods during the two years, so that the occurrence of any possible correlation between tide and abundance may be investigated, should it seem desirable to do so.

While the results of this series of plankton hauls are subject to certain sources of error, they are not affected by some other variants which relate to collecting from a boat. Allen (1921, p. 540) has given a list of conditions connected with boat collecting, and they certainly cannot apply to a set of collections made from a pier. The locations at which successive pier hauls were made could not be farther apart than the width of the pier, for in order to keep the net from being caught on the piling it was towed on the side away from the set of the surface drift. The rate at which it was drawn was practically uniform, since there could be no error due to drifting as there is in hauling from a boat. It is assumed, and is a fact which is reasonably certain, that the length of the haul was the same for all the hauls.

This particular series of collections is of unusual value in the following respects. (1) There has never been another series extending over such a long time, in which so many collections were made during each twenty-four hour period. In this particular at least, our series is unique. The work of Herdman and his associates extends through fifteen years, but their 'official' hauls were taken six times a week (Herdman, 1922, p. 141). (2) The collecting was done at a fixed location. (3) Temperature records were made for every haul, and a water sample from which the salinity was determined was taken at each haul.

My work has dealt only with the Copepoda, which are by far the predominant animals. They are listed under four groups. Two species of the genus *Acartia, A. clausi* and *A. tonsa,* were set down in the lists as species. Other small Gymnoplea have been included in a mixed group called "small calanids;" the group includes the genera *Clausocalanus, Ctenocalanus,* and *Paracalanus,* and perhaps others closely related to them, but no attempt has yet been made to segregate the genera or species. A second mixed group consists of the Podoplea, comprising such genera as *Oncaea, Oithona, Microsetella, Corycaeus,* and others. There is no doubt that valuable facts may be obtained from a study of the occurrence of the genera and species of these two mixed groups, and their separation into at least the component

genera is now in contemplation. In addition to the forms mentioned, several other species occurred rarely and in small numbers, so that their presence need only be mentioned.

When the project of taking such an extended series of observations was being talked over, we felt that a tabulation of results would help in answering such questions as the following: (1) Is there a seasonal variation in abundance of copepods? If so, are the times of maximum abundance similar or different for different forms? (2) Are there diurnal (night and day) variations in abundance? If so, are there generic or specific differences as to the times of greatest abundance? (3) Is there any relation between variations in numbers of organisms and changes in such conditions in the water as temperature, for example, or salinity or acidity?

The results we have arrived at thus far partially answer the first two questions, but correlations between abundance and the other factors mentioned have not been worked out as yet.

In planning the work the intention was that E. L. Michael should handle the statistical part of the results. Before his death in 1920 he had gone over some of the collection reports and had dealt with them by methods developed by him in collaboration with McEwen. Michael's findings were never written up, however, and since his mode of working requires special knowledge of statistical procedure, it has seemed desirable to report on the collections without employing greatly refined methods of handling the data. Those of the present staff who have consulted on the matter believe that even these cruder tabulations show in a general way what has been gained during the two years, and, equally important, show also what has not been gained and whether the plan should be continued with or without modifications.

The method of computing used in preparing this summary was suggested to me by McEwen. The computations start with the average number of animals per haul, arranged under headings for each of the twenty-four months over which the observations extended and for each of the six times of day at which the collecting was done. Such an arrangement of the original data for one species is shown in table 1. The average per haul *for the two years* (last line of table) was used as a standard, and two methods were followed which may be called respectively the "ratio of the means" and the "means of the ratio." By the use of these methods coefficients are obtained which make it possible to correct the original entries, so that in dealing with the

time of day relations the seasonal variability is eliminated and an estimate may be made of the reliability of the results which relate to the time of day.

TABLE 1

Average Number of Acartia tonsa per Haul, Arranged According to Months and Times of Day

Year and month	8 A.M.	Noon	4 P.M.	8 P.M.	Midnight	4 A.M.
1916						
IX	26	12	12	49	198	82
X	4	3	5	37	41	23
XI	40	12	7	74	53	130
XII	24	14	19	19	20	32
1917						
I	9	4	19	5	5	10
II	11	1	1	5	5	11
III	16	5	47	80	83	207
IV	37	10	9	46	59	63
V	4	1	34	93	63	121
VI	5	1	1	82	148	38
VII	11	0	16	97	103	65
VIII	29	36	123	237	304	168
IX	25	2	334	270	60	220
X	14	2	1	43	338	298
XI	35	4	9	32	107	105
XII	11	13	42	85	66	109
1918						
I	8	10	3	58	75	69
II	65	0	0	8	15	28
III	108	0	1	43	28	29
IV	0.3	4	18	58	26	39
V	20	10	0.5	95	76	21
VI	0	3	12	101	67	73
VII	288	947	469	915	1026	1406
VIII	41	24	26	79	175	258
Average	35	47	50	119	131	150

To give an actual example of the way in which the data were handled we may use the figures in table 1. The method of "ratio of the means" is as follows: (1) Add the average numbers of animals per haul at the six periods for the two years. (2) Divide the sum obtained by the horizontal sum of the entries for each month; the quotients are then the coefficients. (3) Multiply each of the original entries (table 1) by the coefficient for the corresponding month; the products are the values corrected for season.

The method called the "means of the ratios" is as follows, referring again to table 1. (1) The ratio of each entry in a column to the

average number of animals per haul for two years as it is given in the same column is determined. This process gives a table consisting of six columns and twenty-four lines. (2) The horizontal sum of each line (step 1) is divided by 6, which gives the coefficients. (3) Each of the original entries (table 1) is multiplied by the coefficient for the corresponding month. These products are the corrected values. This method constitutes a rough check against the first one.

TABLE 2

CORRECTED DATA FOR ACARTIA TONSA, COMPARING THE RESULTS OBTAINED BY THE METHODS OF "MEANS OF RATIOS" AND "RATIOS OF MEANS."

There is also a comparison of the first with the second year.

	Number of animals per haul						Mean ann. abund.
	8 A.M.	Noon	4 P.M.	8 P.M.	Midnight	4 A.M.	
Means of ratios:							
First year	81	25	97	184	478	377	207
Second year	203	41	165	479	684	651	370
Ratio of means:							
First year	49	18	48	118	147	146	88
Second year	68	19	38	124	133	152	89
Two-year average:							
Means of ratios	142	33	131	331	581	514	.....
Ratio of means	59	19	43	121	140	149	.....

The mean annual abundance and the mean monthly abundance of the copepods may both be obtained from the values as corrected by either of the methods. The vertical sum of each of the six columns of corrected values is divided by 24, and the sum of the quotients is then divided by 6 to give the mean annual abundance. The mean monthly abundance is obtained by dividing the mean annual abundance by the coefficient for the corresponding month as derived by step 2 in either method.

The results obtained by using the two methods check fairly well, as differences are usually in the same direction. In table 2 there appear the final results for *Acartia tonsa* as obtained by each of the methods, but for the other forms only the averages for the two methods have been set down.

The probabilities in table 6 were determined from the corrected results by a method worked out by McEwen. The method has not been published, but it has been briefly described (McEwen, 1920, pp. 263, 273). The figures giving the probability indicate the number of times a difference would occur if the results were due to chance. When the values are smaller there is, however, less likelihood that

the results are due to such a cause. The probabilities were determined from results corrected by the ratio of the means and by the means of the ratios, but only the averages are given in this paper.

RESULTS

On the whole the copepods were considerably more abundant during the second year. The totals in round numbers for the two years and for each year separately were as follows: *Acartia tonsa,* total 248,000; 86,000 the first year, and 162,000 the second; *A. clausi,* total 475,000; 182,000 the first year, and 293,000 the second; small calanids, total 330,000; 184,000 the first year, and 146,000 the second; Podoplea, total 4,350,000; 1,210,000 the first year, and 3,140,000 the second. The mean annual abundance, as given in tables 2 and 5, shows that all the forms except the small calanids were found in larger numbers during the second twelve months.

If we consider the corrected values for the six periods (see table 5) it will be noted that there is only one place (8 P.M. for small calanids) where the number of animals per haul during the dark hours is not greater during the second year. During the light hours, however, the larger numbers per haul appear more often during the first year.

It seems evident that the mixed assemblage of genera called "small calanids" constitutes a group somewhat apart from the other Copepoda in occurrence, when one year is compared with another. We cannot say much more than this until the genera and species have been segregated and the results tabulated. It is possible that there are one or two predominant forms whose distribution determines that of the group as a whole.

The values for the mean monthly abundance of the animals show results that are similar to those that are indicated by the total numbers and by the distribution through the twenty-four hours. When the mean abundance for each month is compared for the two years (see table 3), it is seen that for nine months out of twelve the numbers of *A. tonsa* were greater in the second year; in ten months out of twelve the numbers of *A. clausi* were greater in the second year; in seven months out of twelve and in eleven out of twelve larger numbers of small calanids and Podoplea, respectively, were obtained in the second year.

The mean monthly abundance shows clearly the season of the year at which the different copepods were most and least abundant. The

main results may be seen in table 3. *Acartia clausi* was obtained in largest numbers during March of both years. The season of least abundance or of complete absence extends over several months of each year, always covering July, August, and September. *A. tonsa* reached its greatest abundance in August of the first year and July of the second. The smallest numbers were obtained in January and February of the first year, and in March and May of the second.

TABLE 3

MEAN MONTHLY ABUNDANCE. THE TWO METHODS OF HANDLING THE DATA WERE USED AND THE RESULTS COMBINED.

'I' means first year (1916–1917); 'II' means second year (1917–1918).

	Average number of animals per haul							
	Clausi		Tonsa		Small Calanids		Podoplea	
	I	II	I	II	I	II	I	II
September	.09	0	74	114	105	80	1365	1597
October	3	23	22	69	26	54	599	756
November	81	34	61	70	13	51	378	565
December	49	125	35	91	21	166	248	2190
January	72	90	14	53	12	75	181	746
February	95	732	8	46	6	16	536	1259
March	377	1347	80	35	50	103	429	2217
April	54	1025	51	42	38	122	455	2100
May	33	329	33	28	58	58	242	1065
June	26	24	28	66	46	7	682	1254
July	0	28	82	2295	356	71	1755	3226
August	0	21	203	204	167	108	1967	1547

It is hard to say whether the fluctuations from month to month are significant, but there can be no doubt of the general fact that one of the species of *Acartia* is found in greatest numbers at the season when the other species is least abundant.

There is a good deal of irregularity in the monthly abundance of the small calanids, and the results obtained during the two years do not correspond so closely as they do with *Acartia*. During the first year the small calanids showed a well marked maximum in July and a minimum in February. There were two maxima in the second year, in December and April, with the minimum in June. In considering the reasons for these irregularities, we should not forget the possibility that the composition of this mixed group of copepods may have been relatively different in the two years. At least there is nothing to indicate that the differences between the two years may not be due to the occurrence of different genera. It would hardly be expected that the seasonal distribution would show such variability if the

several species comprising the group were present in approximately the same proportions in the second year as in the first.

The Podoplea were present in largest numbers during three months of the first year, September, 1916, and July and August of 1917. They reached their minimum in January. During the second year their occurrence was much more irregular. There was a succession of larger and smaller numbers, the month of greatest abundance being July, followed by March, December, and May. The Podoplea were least numerous in November, with October and January next in order. It is impossible to say what the differences between the two years

TABLE 4

Mean Weekly Abundance of Two Species of Acartia During the Season of Greatest Abundance.

The results of the two methods of handling the data are combined. The figures give the average number of animals per haul.

	Clausi			Tonsa	
	1917	1918		1917	1918
March 1–7	557	408	July 1–7	7	306
March 8–14	835	635	July 8–14	37	226
March 15–21	940	1456	July 15–21	367	5821
March 22–28	127	1705	July 22–28	53	909
March 29–April 4	192	461	July 29–August 4	53	275
April 5–11	32	166	August 5–11	277	754
April 12–18	487	2271	August 12–18	88	242
April 19–25	346	348	August 19–25	343	226
April 26–May 2	90	260	August 26–September 1	154	75

may mean. The suggestion is not out of place, hoewver, that the relative numbers of the forms making up the mixed group were so dissimilar in the two years that the mean monthly abundance must have been different. This suggestion may be verified from the hauls themselves.

In order to compare the two years in another way, the mean weekly abundance of the two species of *Acartia* was determined for the season when the animals were most abundant. *A. tonsa* was most abundant in July and August and *clausi* during March and April. The results appear in table 4. *A clausi* was present in largest numbers during the third week of March, 1917 (March 15–21), and during the week beginning April 12, 1918. But it should be noted that in the two weeks beginning March 15, 1918, there was a marked rise, which was followed by a drop in numbers. After that there came the rise to the maximum. In a general way the conditions of occurrence during 1917 were similar. Although the time of the actual maximum was

different, it was followed by decreased numbers for three weeks, and in the fourth week after the actual maximum there appeared another marked increase which corresponded to the maximum of 1918. A comparison of the two columns in table 4 that deal with *A. clausi* will show that there is a broad similarity in the occurrence of this copepod in the corresponding weeks of the two successive years.

Acartia tonsa reached its actual maximum in the third week of July in both 1917 and 1918. For the next two weeks the numbers

TABLE 5

CORRECTED VALUES FOR NUMBER OF ANIMALS PER HAUL AT THE SIX PERIODS OF COLLECTING.

The results of the two methods of correction are combined.

	Number of animals per haul						Mean annual abund.
	8 A.M.	Noon	4 P.M.	8 P.M.	Midnight	4 A.M.	
First year:							
A. tonsa	65	22	72	150	312	261	147
A. clausi	97	45	97	212	199	210	143
Small calanids	140	94	81	233	99	96	141
Podoplea	1304	990	1240	1425	1353	1480	1259
Second year:							
A. tonsa	135	29	101	301	408	401	229
A. clausi	85	38	40	276	363	391	282
Small calanids	130	51	93	126	119	136	91
Podoplea	1211	884	987	1512	1439	1913	1384
Average for the two years:							
A. tonsa	100	25	86	275	360	331	183
A. clausi	91	41	63	244	281	300	212
Small calanids	185	72	87	180	110	166	216
Podoplea	1257	937	1113	1468	1396	1696	1321

were relatively much reduced in both years. After that there was a noticeable increase during one week, which was followed by a marked drop (August 12–18). The close similarity between the two seasons ends there; but whatever the differences mean the points of correspondence are worthy of note.

In any such investigation as this, the matter of diurnal distribution is sure to come up. A casual examination of the collections will show that there are marked differences in abundance between the day and night hauls. In table 5 there is an arrangement of the corrected figures, and in table 6 are indicated the probabilities that certain of the differences in table 5 are significant.

The changes in abundance that occur between 4 A.M. and 8 A.M. and between 4 P.M. and 8 P.M. are the most important ones, since they

relate to actual diurnal differences. But it is of interest to note the rather marked significance of the difference between numbers obtained at 8 A.M. as compared with noon. As is shown in table 6 the differences between 8 P.M. and midnight, and between midnight and 4 A.M., are of slight significance, but those between 8 P.M. and 4 P.M. and 4 A.M. and 8 A.M. are very strongly significant. On the whole the results show that there is a marked excess of numbers at night, and this excess is not due to chance in the cases of *Acartia tonsa* and *clausi* where the probability has been determined.

TABLE 6

To Show the Probability That the Differences Between Numbers of Animals per Haul at Different Times of Day Are Significant

The figures are based on the corrected values and deal with the two-year averages given in table 5.

	Probability that					
	8 A.M. exceeds noon	4 P.M. exceeds noon	8 P.M. exceeds 4 P.M.	4 A.M. exceeds 8 A.M.	Midnight exceeds 8 P.M.	4 A.M. exceeds midnight
A. tonsa	.0045	.0087	.0005	.00012	.13	see note
A. clausi	.0022	.057	.00037	.0002	.13	.039
Small calanids	.0007	.....	.042	.10	.044	.015
Podoplea	.0495	.....	.028	.02	.....	.045

Note: The number of animals per haul for the two years was greater at midnight than at 4 A.M., and the probability is .165 that the difference is significant.

It will be noted in table 6 that the values under the headings "small calanids" and "Podoplea" are usually larger than those under *Acartia*. This difference is especially evident in the third and fourth columns. The probable reason for the larger values is that the small calanids and Podoplea are mixed groups. It is expected that when the species for those groups have been worked up, the day and night differences will be as great as for the species of *Acartia*.

DISCUSSION OF RESULTS

Since this paper is a preliminary one and in the nature of a report of progress, an extended discussion of the results obtained is hardly necessary. But some facts of general importance have been learned as well as some suggestions regarding methods, and these may well be pointed out. The tables show that there is considerable seasonal variation in the copepod plankton, and the question is always present whether such variability is due to changes in the sea water. It is possible that correlations may be found between the relative abundance of the animals and hydrographic conditions, but, as has been pointed out by Herdman and Scott (1908), hydrographic changes will not deter-

mine the presence of organisms at times when they are not produced. Herdman and Scott (1908, p. 193) state that many seasonal variations are caused "simply by the normal sequence of stages in the life histories of organisms throughout the year." The reasonableness of this statement seems self-evident. In studying the changes of the plankton so far as it consists of Copepoda, it is highly important to know the developmental stages of these crustacea.

The occurrence of phytoplankton undoubtedly has something to do with the occurrence of the Copepoda. The ecological relation between the two groups has not been taken up in the work at La Jolla, though extensive studies of the phytoplankton have been carried on for several years by Mr. Allen. It would be well worth while to know whether there is any relation between the maximal occurrence of a species or group of species of copepods and some component of the phytoplankton. So far as our own work is concerned, however, we must simply state that no facts have been ascertained regarding such matters. But when we consider the well established significance of both phytoplankton and copepods in the food cycle of the sea as affecting certain fisheries (see Michael, 1921, p. 555; Allen, 1921, p. 538; Herdman, 1922, pp. 166–169) the need of ascertaining whether there is a relation between abundance of copepods and, for example, abundance of diatoms, will be emphasized. Aside from its ultimate bearing on fisheries, such a question is worth investigating because of the general relationship it bears to the ecology of the copepods taken alone, since they feed upon the plant cells. Does the seasonal occurrence of the micro-crustacea depend on the occurrence of the organisms on which they feed? May not some of the variability in distribution of the copepods be bound up with irregular occurrence of their food supply? We are not in a position to answer such questions as yet, but they are interesting and important subjects for investigation.

Nothing in our results is more striking than the difference in seasonal occurrence of the two species of *Acartia*. Herdman obtained similar results in his work in the Irish sea, though his tables deal with separate genera instead of species in the same genus. Herdman found, for example, that *Temora longicornis* has its maximum in December, January, and February, while *Paracalanus parvus* is most abundant in September and least abundant in June (Herdman, Scott and Lewis, 1915, p. 233). It is almost certain that just as striking differences will be found between the genera or species of the small calanids and the Podoplea as between the species of *Acartia*.

It may be of interest to note that Herdman (1918, p. 197) found that *Acartia clausi* is most abundant in the Irish Sea from May to October, inclusive, generally reaching its maximum in June with a smaller rise in September or October. At La Jolla this copepod is most abundant in March, and not one specimen was recorded in July, August, or September of 1917. It is hard to account for such striking differences. The conditions are so complex that careful study of hydrographic and hauling data, as well as knowledge of the life history of the animal, would be necessary to give an insight into the matter.

Such of our data as relate to seasonal distribution of the copepods suggest that there is a natural sequence of events year after year. The occurrence of the animals for the twelve months from September, 1916, to August, 1917, inclusive, is not strikingly different from that in the year following. Herdman (1922, p. 145) found the same sort of thing in his work. (See also Herdman and Scott, 1912, p. 154.) While strict uniformity from year to year was lacking, the broad features of the distribution were similar. In our pier series the similarity of distribution in the two years extends even to corresponding weeks, as has been shown in table 4. Our study might be carried farther by ascertaining whether the proportions of different species to the whole catch and to each other are similar at like seasons of different years. If this should prove to be so, it would strengthen the view that there is a rather regular recurrence of phenomena year by year.

Why should seasonal distribution of marine animals be essentially different from that of terrestrial forms, such as birds? It is well known that migrating birds appear in a given locality at about the same time of year, season after season. Minor irregularities from year to year are to be expected, and yet it is true that there is a reasonably regular appearance of a given species.

So in the case of the copepods or other organisms of the plankton, the time of the maximum for one year may lag behind that of another or may occur earlier, without upsetting the view that one year is broadly like another. Surely it would never be found that *Acartia clausi* would appear in greatest abundance in the fall or that *A. tonsa* would reach its minimum in July or August. There is every reason to believe that the times of the maximum and minimum of those two species will be the same year after year.

This series of collections has shown beyond a doubt that the Copepoda found at the pier are more abundant as a group on the surface

by night than by day. The evidence on this point is overwhelming for the two species of *Acartia*. The mixed groups also are present in larger numbers at night, though the differences here are not so significant as for *Acartia*. Since all the hauls were made at the surface, it is not possible to state where most of the animals are during the day; but there cannot be any doubt that the appearance of the larger numbers at night is due to an actual increase in the surface population, and not to inability of the animals to avoid the net in the dark.

The diurnal migration of plankton animals is such a well-known phenomenon that much experimental work has been done in making attempts to ascertain the causes of their movements. *Acartia clausi* and *A. tonsa* have been worked with in the laboratory (Esterly, 1917; 1919, pp. 16–22), and it has seemed from the experiments made there that a possible factor in the migrations is a physiolagical rhythm. Responses to external stimuli, at any rate, do not afford an adequate explanation. So far as the study of the pier collections has gone, the cause of the greater abundance at the surface at night is not indicated, although the fact of the diurnal change is firmly established. It remains to be seen whether more elaborate correlations will give a clue to the reason for the daily rhythm in the sea.

Nevertheless, as has been so often urged in publications from the Scripps Institution, the natural history of the plankton cannot be known until abundant records of both field and experimental observations are available. No amount of experimental work could show that *tonsa* is most abundant in July and August and *clausi* in March. And field observations would never bring to light the physiological rhythm that obtains for both species. It is now possible, for the first time, to set about an investigation of the habits of these two plankton copepods in the light of accurate field data as well as of experimental data.

It may be of interest to call attention to a suggestion that came from the laboratory observations. It was thought that the behavior of the two species of *Acartia* gave reason for believing that the numbers of animals at the surface would be greater during the colder months (Esterly, 1919, p. 22). But our field data show that only *clausi* is most abundant when the water is coldest (March is one of the three coldest months), while *tonsa* is most abundant in July and August when the water is warmest. This instance shows how necessary it is to have field data to check experimental observations.

In conclusion it should be again pointed out that the purpose in mind in taking this series of collections was not to determine the

actual numbers of animals. The aim was to study daily, seasonal, and yearly fluctuations, and to discover whether they were related to variations in environmental conditions; and, if there were such a relation, to ascertain the effect of changes in the different factors. It is believed that the samples obtained are adequate and representative, and that the methods employed are sufficiently reliable to reveal certain broad, fundamental facts. It is uncertain how generally applicable the results are, for in other localities other conditions would prevail. But the investigations have undoubtedly given us a trustworthy view of what may be expected at the pier of the Scripps Institution. As regards methods and suggestions about procedure, it would be difficult to add to what has been said by Allen (1921, pp. 538, 541, 553). It seems perfectly evident that the problems connected with study of the marine plankton cannot be solved until collecting has been done continuously over a long period of years. While our series, which runs through two years is valuable, it is not extensive enough. I believe that when such work is undertaken it should be planned to cover at least ten years. It is doubtful whether there is any need of taking as many hauls in a day as we did, but I am convinced that one haul during daylight and one during the night, at given times, is the least that can be expected to give adequate returns. Collections made at such intervals would undoubtedly be enough to enable us to detect unusual occurrences which might be missed if hauls were taken less frequently. Furthermore, hauls made at some level below the surface, at the same time that the surface hauls are taken, would be extremely valuable. But the most important thing is an unbroken continuity of collecting after the series is once started. Time of collecting, location of stations, kinds of nets, methods of dealing with the data—all these are of secondary importance in comparison with continuity and extent of the series.

SUMMARY OF RESULTS

1. The series of plankton hauls extends over two full years and consists of over 3400 catches. All were surface hauls.

2. The copepods were more abundant at the surface during the second year, that is, from September, 1917, through August, 1918.

3. Two species of *Acartia, clausi* and *tonsa,* are sharply set off from each other in seasonal abundance. *Clausi* is most abundant in March and April, *tonsa* in July and August, while *clausi* is least abundant in July, August and September, and *tonsa* is least abundant in the early part of the calendar year. (See table 3.)

4. The two years of collecting resemble each other even as to the weeks when the species of *Acartia* were most abundant, during the months when they occurred in largest numbers. (See table 4.)

5. There is a very marked increase in abundance of all the Copepoda in the night hauls, and such differences are markedly significant in the case of the two forms of *Acartia*. (See tables 5 and 6.)

6. The facts obtained regarding the seasonal occurrence of *Acartia* suggest that there is a natural and regular sequence of events year after year.

Occidental College, Los Angeles, California.
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